The Strong Interaction and LHC Phenomenology

Theoretical Physics Graduate School course
Dr. Juan Rojo
April 23, 2014

The lectures will take place **Monday** and **Tuesday** each week, **from 9.00 to 10.00 AM**, at the **Fisher Room, Denys Wilkinson Building**, Physics. The first lecture will be Monday April 28th.

1 Outline

The outline of the course is the following:

- **Lecture 1**. Motivation for QCD and historical introduction. The hadron spectrum. Evidence for a new quantum degree of freedom: color. Evidence for a new gauge boson: the gluon. Scaling in deep-inelastic scattering.
- **Lecture 2**. The QCD Lagrangian. Similarities and differences with the QED Lagrangian. Feynman rules. Color algebra and color flow.
- **Lecture 3** Symmetries of QCD. Gauge invariance and gauge fixing. Isospin symmetry and chiral symmetry breaking. Implications for hadron structure.
- **Lecture 4**. Asymptotic freedom. QCD in electron-positron annihilation. Renormalization group equations. The running of the strong coupling constant.
- **Lecture 5**. Jets in e^+e^- annihilation and radiative corrections. Sterman-Weinberg jets. Soft and collinear singularities in the NLO matrix element.
- **Lecture 6**. Jets in e^+e^- annihilation and radiative corrections (II). Cancellation of divergences in real emission and virtual diagrams thanks to a jet definition.
- **Lecture 7** QCD in processes with hadrons in the initial state. QCD factorization and the parton model. Parton Distribution Functions. Sum rules. Experimental evidence for partons.
- **Lecture 8**. The parton model and radiative corrections. Factorization of initial state divergences and evolution of parton distributions. DGLAP evolution equations. The high-energy limit of the DGLAP equations.

- **Lecture 9**. QCD and parton fragmentation. Parton evolution as a semi-classical branching process. The parton shower picture. Monte Carlo event generators and the realistic simulation of the hadronic final state.

- **Lecture 10**. Jet reconstruction in hadronic collisions. Jet algorithms. Jet substructure methods.

- **Lecture 11**. Non-perturbative QCD. The hadronization process and confinement. Non-perturbative models. Underlying event and pile-up in hadronic collisions.

- **Lecture 12**. Determination of the Parton Distribution Function of the proton. The global QCD analysis framework. Quark flavor separation. PDF evolution from low to LHC scales.

- **Lecture 13**. Determination of the Parton Distribution Function of the proton (II). Modern PDF determinations. Constrains on PDFs from collider data. Quantification of PDF uncertainties. Implications for LHC phenomenology.

- **Lecture 14**. Lattice QCD. QCD Lagrangian in a discretized space-time lattice. Non-perturbative information from lattice QCD. Advantages and limitations.

- **Lecture 15**. State-of-the-art QCD at the Large Hadron Collider Matrix element merging with parton showers at LO and NLO. Automation of NLO computations. QCD at the next-to-next-to leading order (NNLO).

- **Lecture 16**. Quantum Chromodynamics and searches for Beyond the Standard Model physics at the LHC. QCD tools for New Physics searches. Impact of QCD theoretical uncertainties at the LHC.

References

[1] M. E. Peskin and D. V. Schroeder, “An Introduction to quantum field theory,” Reading, USA: Addison-Wesley (1995) 842 p

[2] R. K. Ellis, W. J. Stirling and B. R. Webber, “QCD and collider physics,” Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. **8**, 1 (1996).

[3] G. Dissertori, I. G. Knowles and M. Schmelling, “Quantum Chromodynamics: High energy experiments and theory,” International series of monographs on physics, 115, Oxford Science Publications.

[4] G. Zanderighi, "QCD and collider physics", lecture notes available online at http://www2.physics.ox.ac.uk/sites/default/files/QCDLectures.pdf

[5] P. Nason, "Introduction to QCD", lecture notes available online at http://moby.mib.infn.it/~nason/misc/QCD-intro.ps.gz